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(November 1 - November 30, 1963)

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PLAN FOR STUDY OF COMPUTER REQUIREMENTS

Technical Memorandum

CDC TM-9552-6

Feasibility Study of a
Track-While-Scan Navigation Concept

Contract No. NAS1-2902

November 4, 1963

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Monthly Progress Report

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Progress

Two technical memoranda, one reviewing the areas to be covered for the study of computer requirements and one describing these requirements for data input and preprocessing, are attached. About half completed during this month is the area of target identification. Effort was also expended in the area of camera and capsule design.

Next Month

The computer requirements study for target identification will be completed and work begun on the solution of the equations. Also, design efforts will proceed.

Joseph E. Carroll
Project Engineer

Attachments

PLAN FOR STUDY OF COMPUTER REQUIREMENTS

Abstract

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This memorandum outlines the various areas of study to be pursued under the Computer Requirements phase of the NASA contract. The navigation equation, whose solution is necessary to derive information from the scanning camera, will be studied for memory requirements, necessary subroutines, and computation speeds. Also the desirable features of a space computer to perform these operations will come under scrutiny, including such considerations as buffered input of camera data, instruction repertory, and types of storage. It is planned to study these areas in some detail, deriving design criteria, success probabilities, and flow chart sequences for implementing the scanning camera navigation concept.

Author

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PLAN FOR STUDY OF COMPUTER REQUIREMENTS

INTRODUCTION

The requirements imposed on a computer for the implementation of the scanning camera navigation concept are to be studied as specified in items 1, 2, and 4 of the work statement for contract number NAS1-2902. As a beginning on this phase of the contract, the present memorandum reviews the areas to be studied and the goals toward which effort is to be directed.

Two areas are evident: Software and Hardware. The first essentially defines those requirements for "solving the problem"; that is, for gathering data, identifying targets, and solving the navigational equations. The study of "Hardware" will be more concerned with the computer itself: word length, memory, instructions, etc. During this phase of the contract, study will be devoted to the individual components of each area. An evaluation will be made of: the number of storage locations required, the number of elementary operations of various kinds, and the speed of computation.

The intent in the present pages is to relate the various parts, outline the method of attack in each area, and especially to define the problem together with those assumption basic to the study.

In general, what is desired from this phase of the contract is a set of flow chart sequences for the various tasks involved in computation of vehicle attitude and position. In addition, we want to define those features of the computer which are most desirable for our purposes and assess their value in terms of computation speed and number of memory locations required. In a nutshell, we wish to show that the navigation technique is feasible, requiring only reasonable demands on present-day computer techniques.

Following is a brief statement of each of eight topics to be studied. In general, two assumptions are most significant:

(a) The camera instrumentation will be separate from the space vehicle and its motion will follow that of a rigid body symmetric about the desired spin axis. It will be spun up about the symmetry axis, though some precession (but not nutation) will remain due to release errors.

(b) The computer will be assumed to have, in addition to the normal complement of arithmetic and data transmission instructions, the internal capability of multiply, divide, and search, and some method of high-speed buffer input. Requirements when these do not exist will also be studied, but not in as great detail.

I. SOFTWARE REQUIREMENTS

These will be studied under the headings: data input and output, target identification, target position correction, determination of approximate attitude, and solution of the navigational equations.

A. Data I/O

This is to be studied in parallel with such hardware items as buffer input and interrupt features. Principally one is concerned with the acceptance and storage by the computer of data from the camera. During each rotation period, the camera will detect about thirty targets (using the 100 brightest stars and 9 planets). Measurement of transit time and intensity at each of two slits will thus produce 120 pieces of information during a single scan. Thus, consideration must be given to trade-off between the probability that information will "pile up" and the basic speed of the computer. Assuming uniformly distributed transit times, a memory cycle of 2.5 μseconds, and a spin period of 10 seconds, one can expect to lose an average of one target out of every 40,000.

This is certainly negligible and a "reasonably fast" computer would not then be a bottleneck. The detection process itself forms a far greater problem. For a 10 second spin period, a star takes 368 μseconds to cross a 20 second of arc slit (inclined at 30° to the vertical). Now each slit sees thirty targets during one period. If separate electronic instrumentation exists for each slit, and the targets are uniformly distributed, then we will lose, on the average, one target out of every 906 or about one target in 30 scans. This is still not noticeable and should not cause any serious navigational difficulty.

Concerning the output of data, it may prove desirable to control the bias levels on the photomultiplier.

B. <u>Target Identification</u>

This subject forms a most crucial aspect of the system. For without it, the camera information is sterile since the navigation equations are target dependent. It is planned to use a combination of scan-to-scan searching, magnitude and separation angle pairing, and a reliance upon measurement accuracy to complete the recognition. The study will also include an estimation of the decision values used in these searches.

More precisely, it is first planned to find two bright targets in each of the two slits during one scan which have nearly equal (allowing for precession effects) time separations. If their intensities also match within limits, then these are tentatively taken as belonging to one another. Moving down the lists for each slit an amount nearly equal to the spin period (again allowing for precession, spin-up, and release errors) we try to find the same pattern of pulses. After this pattern has been identified in each scan period, it forms a method of better estimating the period and establishes "bench marks". From these, other fainter pulses can be paired and so on until enough targets have been assembled for the navigation section.

It is to be noted that the targets are still not identified, but also that 'false' pulses will rather easily be eliminated since they do not repeat from period to period.

To finally identify the targets, we use a combination of angular separation between pairs and intensity matching for tentative identification. The identification of one target is accepted, say, after pairing with two other targets has given consistent results.

C. Target Position Corrections

Because of the high accuracy (10 seconds of arc) desired for target position location, some of the stars and especially the planets will have to have their ephemeris positions corrected due to: aberration, the finite velocity of light, proper motion, and parallax. These corrections of course, depend on vehicle velocity, position, and the duration of the mission.

For example, a flight out to Saturn's orbit requires that about four stars be corrected for parallax (to 2 seconds of arc) while a mission of ten years duration requires the correction of about 28 stars for proper motion.

D. Approximate Attitude

The navigational equations are highly non-linear in the attitude parameters. Hence their solution for these quantities will be accomplished in an iterative fashion starting from an assumed initial set of values. The determination of these initial values, however, will in some cases not be easy. This is due to the fact that some of the Euler angles describing attitude become indeterminate when others go to zero. But it will be the duty of the navigator to spin the camera in such a manner that this is nearly what happens. To specify beforehand what the values of these almost indeterminate angles should be is thus impossible. Further, for the navigator to make an "eye-ball" measurement of these angles will also be highly difficult.

A possible solution is to compute from a restricted number of transits and a simplified attitude motion the approximate parameters to be used a s initial values in the iterative process. A study will be made of this entire issue since convergence to false values is a distinct possibility in problems of this nature.

Position does not suffer a similar difficulty in this sense since it occurs linearly in the equations and can be solved for explicitly.

E. Solution of Navigation Equations

The navigation equations will be solved in two steps. First, all star transit times will be used to determine by a least squares method the vehicle attitude. This will require several iterations using initial attitude values as mentioned in part I-D above. It will be assumed that the camera is spinning about its symmetry axis while slowly processing about the angular momentum vector. The number of unknowns is six (three for initial attitude and three more for initial attitude rates).

The second part of the navigation problem is position determination. The computed attitude will be used together with planetary transit times. This is a much simpler problem since the number of unknowns is only three and these are linear in the equations. Thus only a three by three matrix need be inverted and no position approximations are required (this latter is not strictly true, but no indeterminacy exists as it does with attitude).

The task of this section will be to determine the memory and speed requirements needed to solve these equations together with an examination of such trade-offs as power of the computer instructions versus required memory for lesser commands.

II. HARDWARE REQUIREMENTS

These will be studied under the headings: input-output equipment, instruction repertory, and storage requirements. The factor of execution speed enters into all of these and so does not form a separate topic.

No attempt will be made during the planned study to design the computer, but only to estimate those desirable features useful in solving problems of the type under study. On the other hand, if these demand special design considerations, they will of course be included.

A. Input/Output Equipment

In Section I-A, data rates as they affected memory cycle time were discussed. There it was assumed that the computer used all of its time in waiting for the camera, even though such data comes at a relatively low average rate. It might prove useful for the computer to proceed with computation when not receiving and storing data. This, however, would require two features, the feasibility of which and need for which will be studied under this phase.

The first is a high-speed buffer capable of holding several words of information and also capable of operating separately from the main computer. The function of this device would be to accept camera data and automatically store it sequentially in order of receipt and at a very high rate. This would reduce the problem of information loss due to lock-out and would permit other operations to be performed during the data acquisition mode. The examination of the details of the camera-buffer interface and also buffer capacity will form part of the study.

The second desirable feature is interrupt. This denotes the ability of the computer to cease what it is doing, execute a totally unrelated sequence, then return to its original task. Hence, in the data acquisition mode, the main computer is informed when a word of data is received by the buffer from the camera. When it completes the current elementary operation, the computer then empties the buffer, stores this information appropriately, and returns to its original sequence until receipt of the next interrupt signal.

It is almost certain that interrupt will be incorporated into a space computer quite apart from the considerations of navigation. The use of this feature along with a high-speed buffer will easily permit the computer to, say, partially analyze the camera data prior to identification.

B. Instruction Repertory

From the standpoint of capability, the two most important things are speed and the power of the elementary operations. Quite obviously, weak instructions will require excessive storage and long computation times. On the other hand, powerful instructions make the computer itself larger, heavier, and more susceptible to failure because of increased complexity. It does seem that a quite satisfactory compromise can be reached by incorporating instructions such as add, multiply, divide, shift, scale, and search. These are certainly quite powerful, but do not require extreme complexity of design.

It should be noted that the arithmetic operations suggested are also recommended to be in fixed point. This means that those intricate and accurate computations which require floating point (matrix inversion, e.g.) will have to be constructed by programming techniques which can incorporate the scaling instructions to great advantage. For example, a floating point multiply could be a subroutine which the main program jumps to each time such an operation is called for. This does not excessively increase storage requirements, but may increase running time somewhat. It appears that a floating point operation on a fixed point machine takes on the order of six times as long to execute. This delay can to some extent be offset by increasing the basic speed.

Search instructions would greatly simplify the star identification problem. One simplified method of implementing a search within limits would be through the use of a "Greater-than skip" and a "Less-than skip" instruction capable of address modification (indexing) and in which the contents of the accumulator were not destroyed. It is also desirable to increment the contents of memory address and address modifiers without the use of the accumulator.

The word length used is especially important since it is directly related to size and weight and also to computation accuracy.

The word length should probably be in the range of 25 to 30 bits. Fourteen seconds of arc angle accuracy is fractionally equivalent to between 16 and 17 bits. The same is true of position accuracies of 300 feet in 6,000 miles. To avoid round-off errors in complex subroutines or matrix inversions, one might arbitrarily add another four bits. Note, however, that this is only fractional accuracy and that the numbers encountered in problems of this type can have a rather wide range of values. Including another six bits for the power of ten will thus permit the handling of numbers as small as 10^{-32} or as large as 10^{+32}. Combined, these estimates give 26 to 27 bits for the desired word length. Now it is also true that not all operations need be performed in so accurate a fashion. Much of the time will be taken in simple housekeeping such as indexing which may only require a few bits at a time. In these cases, it may be highly desirable to have the capability of using smaller words thus increasing the speed of such operations.

It is not possible to firmly establish the computer speed requirements without a more detailed study. It is felt, however, that a moderately high speed computer (3 to 5 microseconds add instruction) is required, not so much because of high solution rate requirements, but chiefly because of the enormous amount of data processing required. It is assumed that the major portion of the computer time will not be spent in performing arithmetic computations but rather in data processing, searching, and testing.

C. Storage Requirements

Another factor in the determination of computer size and versatility is the amount of memory required for each of the various tasks. A space computer will be engaged in many operations, but we shall concern ourselves only with those requirements needed to implement the scanning camera navigation concept.

More specifically, the number of storage locations needed for each of the tasks outlined in Section I will be assessed. Attention will be given to the necessary subroutines (sine-cosine, square root, arctan, floating point, etc) and round-off and truncation errors. Permanent and scratch pad sections inside the main computer memory together with auxiliary devices such as drums, tapes, etcetera for external storage of data and programs will also be considered.